Interpolation in between Road Measurements in RF-EMF Exposure Assessment

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SUMMARY

In some European countries, radio communication agencies carry out large-scale radiofrequency (RF) electromagnetic field (EMF) measurements for ether regulation. In this study, we assess the possibility of using this existing database for the assessment of RF exposure over large areas. Using a car-mounted frequency-selective measurement system, signals from mobile-phone base stations in the 900 and 1800 MHz bands were measured within and around a residential area. Then we interpolated the data on the edge (along both a closed and an open loop) complemented with increasing amounts of inner data to achieve progressively accurate exposure models. Through analysis of a 50-point validation, we found that 80 inner data points per km^2 could be sufficient to obtain an accurate interpolation model.

INTRODUCTION

In the Netherlands, a large database of densely measured radiofrequency monitoring data of the Radiocommunications Agency Netherlands is available, covering a majority of connecting roads as well as the streets of the four largest cities. Recently, the Netherlands Organisation for Health Research and Development (ZonMw) project E-Monuments successfully explored whether this kind of ether regulation measurements can be applied for exposure characterization [1]. Now the follow-up ZonMw project KRABBELEN aims at modeling the fields in between the grid of roads by means of geospatial interpolation techniques, in particular, Kriging.

This paper describes the followed steps in the KRABBELEN project. Using distinct data sets containing electric-field measurements around the area under study (*edge data*) and inside the area (*inner data*), consecutive interpolation models were built employing increasing amounts of inner data. Validation analysis gives us insight in how much inner data (per km^2) is needed to complement available edge data in order to obtain an accurate model of the RF-EMF exposure inside the area. Additionally, we compared the results of two outer data sets, one corresponding to a closed loop around the area, and the other to an open loop.

MATERIALS AND METHODS

In the E-Monuments project [1], RF measurements in the 900 MHz (GSM) and 1800 MHz (DCS) bands were performed in a residential area in Amersfoort, the Netherlands (Figure 1). A frequency-selective measurement device of type RFeye (CRFS Ltd., Cambridge, UK) consisting of an integrated spectrum analyser, a GPS tracker and a data storage facility was installed on the roof of a car (at approximately 1.5 m above the ground), collecting samples of the power density every 2 seconds, while the car was driving at an average speed of 30 km/h. The area was subdivided in tiles measuring 35 m by 35 m, and the average power density per tile was calculated from all collected samples within that tile. For both frequency bands, three data sets were collected: (1) measurements along a closed loop at the edge of the area under study (*edge closed-loop*), (2) measurements along an open loop around the area (*edge open-loop*) – which is slightly bigger than the area within the closed-loop, and (3) measurements within the area (*inner*). Each loop was covered twice: once in clockwise and once in counter clockwise direction.

Two sets of interpolation models were built from the measurements on the edge of the area (one with the *edge closed-loop* data set, and one with the *edge open-loop* data set) complemented with a random subset of *inner* data points, subsequently adding more points and thus covering more of the inner area, with the aim of enhancing the interpolation. More specifically, 11 subsequent models were built, using 0 to 100% of the inner data subset (after removing inner data points on the edge of the area, as well as setting aside a subset of 50 data points for model validation). Before kriging interpolation, the power density measurements were converted to logarithmic values. Validation of the resulting interpolation models was averaged over 50 runs, each run randomly dividing the *inner* data in model building data and validation data (50 points).

RESULTS

A summary of the GSM and DCS power density measurements along the two loops and in the inner area is given in Table 1. Along all measurement trajectories, a lower exposure contribution is found for DCS (on average 6 to 10 times lower than GSM). The two outer loops show a similar power density distribution for both GSM and DCS, with higher measured values than in the inner area (on average by a factor 2 to 4).

In total, 200 inner data points were available to complement the edge data (168 points in the closed loop, 139 in the open loop) to build the interpolation models. The model validation results are shown in Figure 2 (a) for GSM and (b) for DCS. Although a high correlation is achieved even without adding inner data, the possible prediction errors are high (average relative bias 100 to 350%). However, the relative bias quickly decreases by adding inner data, and relatively stable validation metrics are obtained once 10% of the inner area (here, 80 inner data points) is covered, namely a Cohen’s kappa of 0.5 to 0.6, a specificity of 0.94 to 0.96, a Spearman’s rank correlation coefficient of 0.80, and a relative bias of ~50%.

As the power density is averaged over tiles of 35 m by 35 m, a covered inner area percentage of 10% corresponds to approximately 80 tiles per square kilometre.

Moreover, using a closed-loop edge data set results in slightly better validation metrics, although the magnitude of improvement decreases with increasing covered inner area.

CONCLUSIONS

From the results in our test area in Amersfoort, we can cautiously conclude that our approach is sound, and that a relatively accurate interpolation model of the RF-EMF exposure within an area can be built using measurements on the edge complemented with measurements in ten percent of the inner area, which corresponds to about eighty tiles of 35 m by 35 m per square kilometre. In the future, more areas of diverse shape, size, and RF exposure will be investigated, and the correlation between area characteristics with the validation results will be studied.

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data set	signal	min ($\mu W/m^2$)	max ($\mu W/m^2$)	mean ($\mu W/m^2$)	std ($\mu W/m^2$)
inner	GSM	1.03	1399.41	67.07	144.29
(n = 250)	DCS	0.02	189.35	6.47	20.07
closed loop	GSM	3.43	2133.15	170.84	369.98
(n = 168)	DCS	0.08	544.76	28.36	88.11
open loop	GSM	4.60	1983.42	135.07	289.63
(n = 139)	DCS	0.12	506.16	23.40	82.34

n = number of points in data set, min = minimum, max = maximum, and std = standard deviation.

Table 1: Summary of power density measurements in the inner area, and along the closed and the open loop.

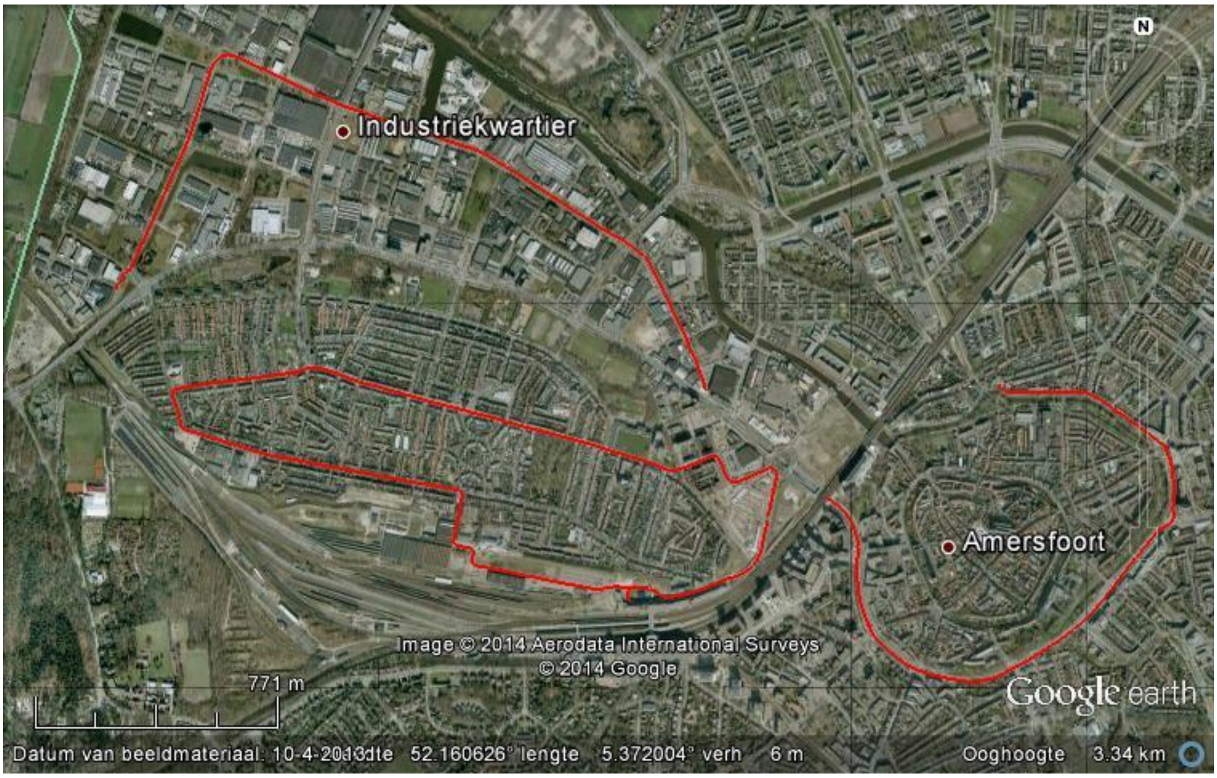
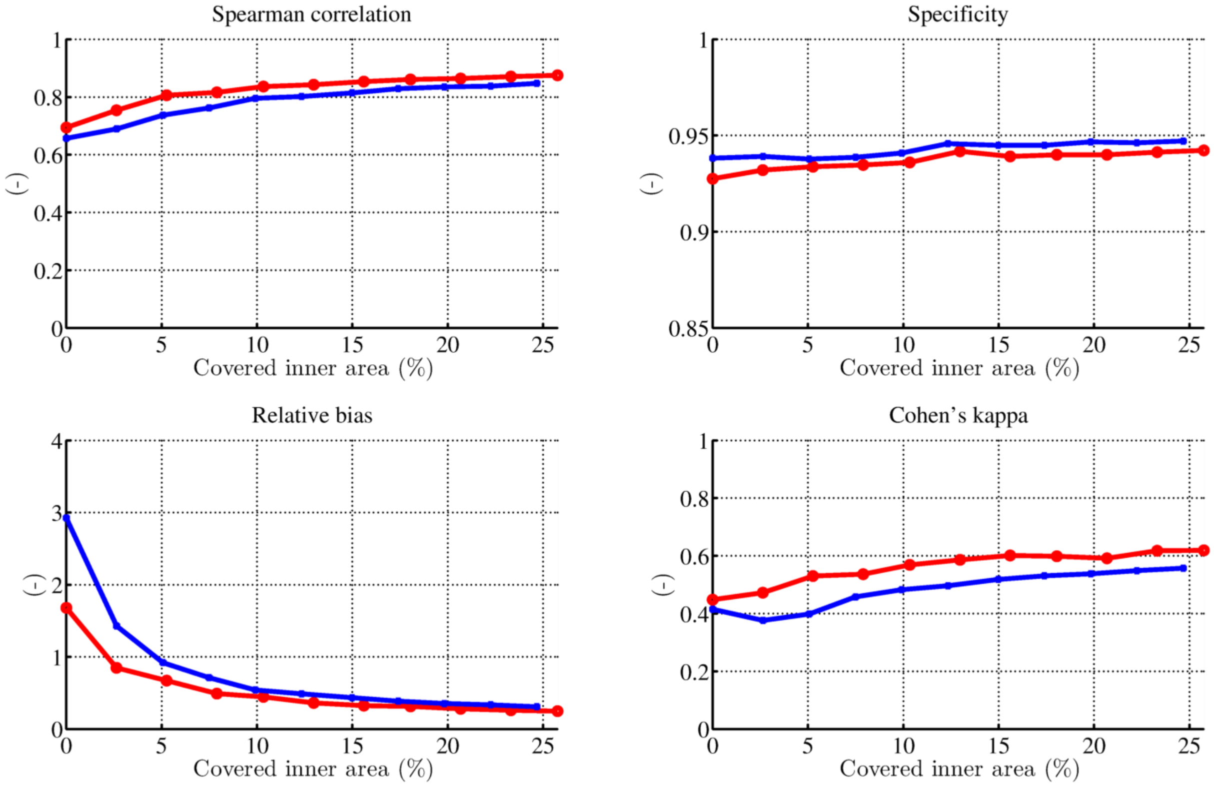
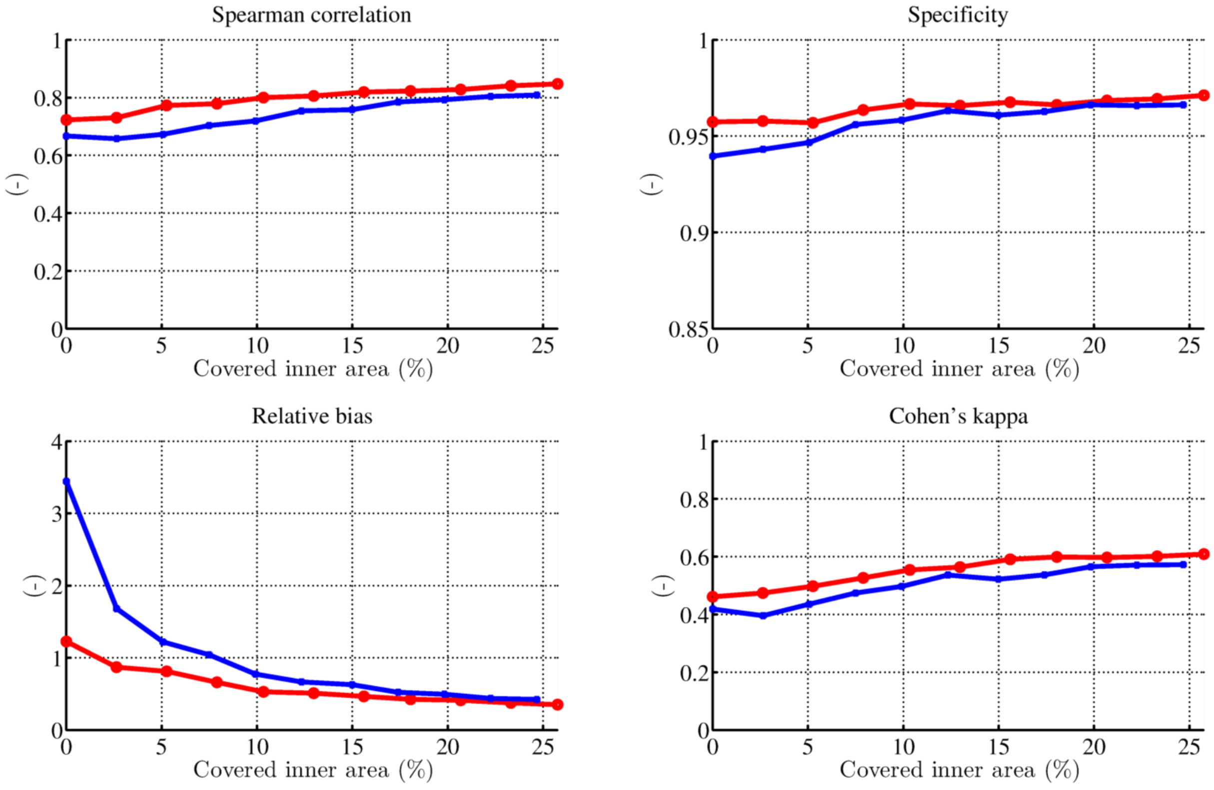


Figure 1: Itineraries in Amersfoort, NL: Isselt (industrial, upper left), Soesterkwartier (residential, lower left), Innerring (city, lower right). Courtesy, ©2014 Google,©2014 Aerodata International Surveys, ©2014 Infoterra Ltd. & Bluesky.



(a)



(b)

Figure 2: Correlation (Spearman's rank correlation coefficient, specificity, and Cohen's kappa) and error (relative bias) metrics as a function of the percentage of inner area covered by the model building data for **(a)** GSM and **(b)** DCS. The red lines with dots correspond to the closed-loop models, the blue lines with crosses to the open-loop models.